RUNOFF SAMPLING: COSHOCTON VANE PROPORTIONAL SAMPLER

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ABSTRACT

This sampler collects a composited representative sample of runoff from each storm event at sites where flow is measured by a broad-crested or similar overfalling weir. The sample can be used to determine average concentrations and total transports of liquid and suspended solid components of the runoff event.

Proportionality is maintained by a revolving vane and movable outfall that collect a consistent fraction of all runoff above a threshold or base flow level. Timer and double vane options provide for adequate sample volume from large or small runoff events. The sampler uses only basic electrical and mechanical components and has performed well on watersheds as large as 300 acres where the maximum design flow rate is 500 ft^3/s.

Key words: Runoff sampler, Automatic sampler, Sediment sampler, Water quality, Stream sampling

Factors for converting from English to metric units of measure

To convert	Into	Multiply by
Inches	Millimeters	25.40
Feet	Meters	.3048
Acres	Hectares	.4047
Cubic inches	Milliliters	16.39
Cubic feet	Cubic meters	.02832

RUNOFF SAMPLING: COSHOCTON VANE PROPORTIONAL SAMPLER[1]

W. M. Edwards, H. E. Frank, T. E. King, and D. R. Gallwitz[2]

INTRODUCTION

Current interest in the quality of environment emphasizes the need to know how we influence the surroundings by what we do. From the hydrology and water quality standpoint, farm chemicals applied on cropland can move in overland flow systems and be transported downstream where they become a matter of concern.

On small, field-sized watersheds, runoff occurs during and for a short time after excessive rainstorms or snowmelts. Runoff from such areas has been sampled for many years with volume integrating samplers (*8*)[3] and devices that take several discrete samples within a runoff event (*2, 5*). At some point downstream, however, runoff becomes more or less continuous. Low volume flow in these downstream channels is generally clear and of good quality, but wet season flow and runoff from high-intensity storms on the watershed above transport variable concentrations and amounts of sediments and chemicals.

Sampling storm runoff is difficult at these downstream sites where the peak flow rate may be 1,000 times greater than the base flow rate. Usually, discrete samples are collected at different times during a runoff event, and total transport is calculated by multiplying representative volumes within the event by concentrations determined on several samples (*1, 6, 7, 9*).

For some objectives no alternative may exist to analyzing several samples for each event (*4*), but for others a single representative sample is adequate (*3*). The Coshocton Vane Proportional Sampler was developed to eliminate the high cost of analyzing several samples per event when only one representative concentration value is needed.

The Coshocton Vane is designed to colle
proportionally integrated sample from the
at a watershed weir and to deliver it to a ref
ated container. Proportionality is effected
moving pump outfall and rotating va
work together to sample a
flow passing the measurin
operate at weir and flum
and flow rates are to
Coshocton Wheel (*8*) and where coarse fragments (>2 mm) settle out in the pool above the measuring structure. It can be easily adjusted to begin sampling at any predetermined stage, eliminating base flow sampling when warranted. The sampler has performed well on Coshocton watersheds ranging in size from 40 to 303 acres where runoff is measured with broad crested triangular and Columbus deep-notch weirs.

[1]North Appalachian Experimental Watershed, Agricultural Research Service, U.S. Department of Agriculture, Coshocton, Ohio, in cooperation with the Ohio Agricultural Research and Development Center, Wooster, Ohio 44691

[2]Soil scientist (ARS) and associate professor at OARDC, hydrologic technician, biological technician (soils) and electronics technician. North Appalachian Experimental Watershed. Agr. Res. Serv., U.S. Dept. of Agr., Coshocton, Ohio 43812

[3]Italic numbers in parentheses refer to Literature Cited, p. 7.

SAMPLER DESCRIPTION

Flow System

Figure 1 is a schematic description of the sample flow system. The intake is in the turbulent pool below the weir. A submersible pump delivers a continuous flow into the sampler shelter, which is located at an elevation above flood stage. The pump delivery rate is preset by valve A to give a manageable sample volume before delivery through flexible tubing to outfall B above the rotating vane C. The position of the outfall is controlled by the level of the float D in a stilling well. One end of the wand E is pinned to the float tape, which moves the outfall as the water stage changes. Low-friction wheels G transform the vertical movement of the float and weight F to a horizontal movement, controlling outfall position. Mercury switch H is supported by an adjustable stop I on the float tape which sets the on-off level of pumping. Motor J, which revolves the vane shaft K at a constant speed, is also activated by switch H.

The sampled portion of the pumped flow is caught by the vane and is delivered by gravity through a funnel L and delivery tube to a sample container in a refrigerator. The pumped flow that is not caught in the revolving vane is returned to the stream through a floor drain.

Wand

Wand design and operation are shown in figure 2. The wand is a ½-inch rigid plastic tubing, supported at one end by the float tape and at the other end by a metal ring through which the wand slides as the water stage changes. At A, the end of the wand is loosely pinned to the float tape.

The pivot ring near the other end of the wand at C is positioned so the length of the wand at zero stage (A to C) and at maximum stage (B to C), and the length of float tape between zero and maximum stages (A to B) form the sides of an equilateral triangle. This restriction is imposed to standardize and simplify the calculations for vane shape.

The purpose of the wand is to reduce the outfall movement to something less than the float

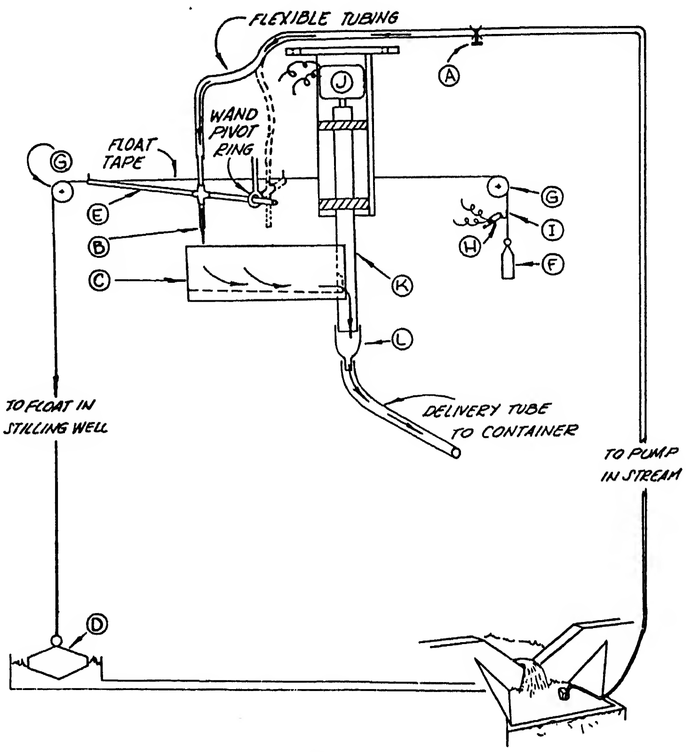

FIGURE 1.—Schematic of sample flow system and sampler components that move the pump outfall and revolving vane.

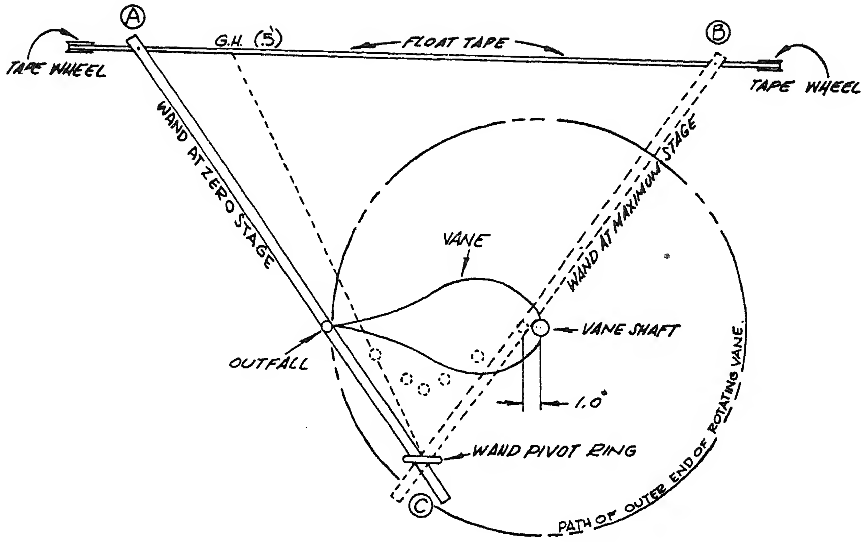

FIGURE 2.—Top view showing the relative positions of the wand, pump outfall, and revolving vane.

movement. At some of the Coshocton sites, the maximum design stage is 4 feet. If the pump outfall was attached directly to the float tape, the outfall would move a distance of 4 feet and the sample vane would have to be over 4 feet long. A revolving, 4-foot vane requires a shelter at least 8 feet in diameter and necessitates building the vane assembly out of much heavier, stronger, and more costly material.

By positioning the pump outfall at some point on the wand between the tape pin and the pivot ring, the outfall movement and vane length are reduced. The relative position of the outfall on the wand is determined by the desired reduction in outfall movement with respect to float movement. For example, if the outfall is located one-third of the way from the pivot ring to the tape end at zero stage, the vane length will need to be only one-third of the distance from zero to maximum stage.

Vane

Construction and mounting details for the vane assembly are shown in figure 3. The vane sides are 0.01-inch stainless steel soldered to a 1-inch copper pipe vane shaft. Sampled water flows from the vane through an opening into the shaft just above the sealed, wood vane floor.

The vane shaft is supported at two points by bearings that are held tightly by hose clamps in the 2-inch angle iron support. The support is bolted to the shelter roof, keeping the vane shaft vertical. The 4-r/mi (revolutions per minute) vane driver motor is linked directly to the top of the vane shaft. The vane stop position switch, which stops the vane at the same place each time, is also mounted on the angle iron support. A small hose clamp tightened onto the vane shaft acts as a cam to operate this microswitch.

The vane stop position switch is required to insure that the pump outfall will be delivering at

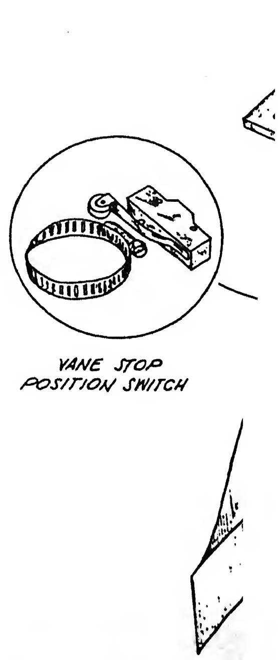

FIGURE 3.—Construction

capacity when the vane next passes under it. Without the vane positioning function, the vane could stop just ahead of or directly under the outfall, possibly decreasing or increasing the catch.

The vane is shaped to collect a constant fraction of the flow through the weir on every revolution of the vane, regardless of stage. For example, if the flow rate at a 2-foot stage is seven times the flow rate at a 1-foot stage, the sampler must collect in each pass under the pump outfall seven times as much as it does at the 1-foot stage. Because the delivery rate through the pump outfall and the r/mi of the vane do not change with stage, proportionality is obtained by varying the length of time that the vane is under the pump outfall. This is accomplished by moving the pump outfall closer to the axis of rotation of the vane as the stage rises and by making the vane wide enough at all stages to insure proportionality.

The exact vane shape is determined by the weir rating table and the position of the vane shaft with respect to the wand. To simplify the development of a computer solution for calculating vane dimensions, we standardized on the relative positions of the wand and vane shaft as shown in figure 2. The vane shaft is positioned 1 inch away from the line BC when measured parallel to the float tape. The position of the outfall at 0 stage, at maximum stage, and the vane shaft must all be in a straight line parallel to the float tape. These last two requirements locate the vane shaft with respect to the wand.

Vane Shapes

Graphical solution

Calculations for vane shape are shown in table 1. The first two columns come from the weir rating table. The selected gage height (GH) intervals do not have to be constant but must cover the range of expected flow. Column three lists the sampling radii for each gage height. These values are measured from a graphical plotting similar to figure 2. If A, B, C, the pump outfall, and the vane shaft are plotted to scale on graph paper, the outfall at intermediate gage heights can be located as shown by the dashed line in figure 2 for gage height 0.5 foot. The measured or calculated distances from these intermediate outfall positions to the vane shaft are recorded as R (column three of table 1).

Table 1.—Calculations of vane shape using graphical measurement of sampling radius

GH	Flow rating	R = [1] Radius	Ratio[2] S(I)/S(1)	S	D = R cos S/2R [3]	W = 2R sin S/2R [4]
Feet	Ft³/s	Inch		Inch	Inch	Inch
.5	0.903	11.95	1.000	0.286[5]	11.95	0.29
1.0	5.39	10.00	4.995	1.428	9.98	1.43
1.5	15.9	8.38	12.348	3.532	8.20	3.51
2.0	32.7	6.55	19.849	5.677	5.94	5.50
2.5	59.3	4.12	22.641	6.475	2.91	5.83
3.0	94.7	1.00	8.776	2.510	.31	1.90

[1] Radius = distance between outfall and vane shaft.

[2] Ratio $\frac{S(I)}{S(1)} \times \frac{Ft^3/s(I)}{Ft^3/s(1)} = \frac{Radius(I)}{Radius(1)}$

[3] D = distance from vane shaft (see fig. 4).

[4] W = width of vane at distance D (see fig. 4).

[5] S(1) = 0.4 × 2π × Radius(N) / Ratio(N), where N is number of entries in table 1. For I>1, S(I) = Ratio(I) × S(1).

The ratio column gives the relative path length (S of fig. 4) across the vane as a multiple of S at the lowest gage height considered, S(1). These ratios and S(1) are calculated as shown in footnotes 2 and 5 of table 1. The remaining values of S are the products of the ratios times S(1).

The last two columns of table 1 give the design dimensions: width W as measured perpendicular to the centerline of the vane at distance D from the vane shaft (fig. 4).

The lowest stage considered in table 1 is 0.5 foot. If lower stages are to be sampled or if additional intermediate points are desired to insure an accurate representation of the flow at all stages, additional calculations for any positive gage heights would be as those shown in table 1.

D for the 0.5-foot stage is 11.95 inches (table 1), which means that the vane revolves within a 1-foot radius. The outfall for this example is about one-third of the way from the wand pivot ring (C) to the tape end of the wand (A) of figure 2. If the

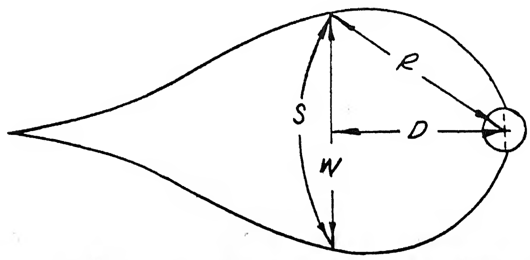

Figure 4.—Top view of vane showing dimensions used in calculating vane shape.

outfall was farther from the pivot end of the wand, a longer vane would be needed.

Computer solution

Appendix A is a Fortran IV program for calculating vane shape when the wand and vane shaft positions are as shown in figure 2. Appendix B shows program input and output for vane shape dimensions for a hypothetical broadcrested weir.

For the appendix B example, maximum expected stage is 3 feet with rating table input given at 3-inch intervals. As shown in column four, the resulting vane length becomes nearly 18 inches if water stages as low as 3 inches are to be sampled.

Input to the program is contained on three cards:

Card 1:

Number of gage height-cfs pairs to be read on cards 2 and 3, that is 12

Approximate vane length, that is 18.0 in.

Site identification number, that is 999

Cards 2 and 3:

Paired gage heights (feet) and flow rates (ft^3/s), that is, 0.25 .180; 0.50 .903; . . . 3.00 94.7

Electrical System

The sampler operates on 120 Vac line voltage as shown in the electrical schematic diagram (fig. 5). A rising runoff stage closes the float operated water level sensing switch S1, which allows current to flow to the mode of operation switch S2. If S2 is in the continuous operation position, the circuit is completed to the pump and rotor motors and sampling continues until the stage drops low enough to open S1. If S2 is in the timer position, the timer motor will run as long as S1 is closed.

The timer motor drives an adjustable, split disk cam which operates S3. When S3 is in the NC position, the sampler is operating. When the timer cam causes S3 to reverse its contacts, the circuit is completed through the NO terminal and sampling continues until the circuit is broken by S4, the vane stop position switch. Switch S4, which is controlled by a cam on the vane shaft (fig. 3), stops the operation immediately after the vane completes its next pass under the pump outfall. The sampler is then idle until S3 reverses again to the NC position, restarting the pump and vane rotor.

With a 4-r/mi vane rotor (table 2), the vane makes 20 passes under the pump outfall in 5 minutes when S2 is in the continuous mode. When S2 is in the timer mode, the timer cam can be adjusted to operate the sampler for as few as 1 or as many as 19 passes every 5 minutes.

Switch S5 is a manual bypass of S1 used for checking and calibrating the system.

A pilot light is included to give visual indication that the system has been activated. The sampler draws less than 5 amps using the components listed in table 2.

Table 2.—Electrical components for Coshocton Vane sampler

Component	Description	Source[1]	Cost
S1	SPST mercury switch	1	$ 1.75
S2	SPDT toggle switch AH 80609—CA	1	2.96
Cycle timer S3	SPDT cammed microswitch GT-RG21-094	1	18.05
S4	SPDT microswitch BZ-ZRL25551-AZ	1	4.85
S5	SPST toggle switch AH 80601-BD	1	2.96
Vane rotor	Sychronous, 4 RPM Hurst, model DA	1	21.05
Pilot light	115v Chi. miniature 5756-3 oz—116	1	1.61
Pump	Submersible, Little Giant model 3E-12n	2	40.84
Total			$94.07

[1] 1: Hughes-Peters, 418 E. 11th Street, Columbus, Ohio 43211

2: W. W. Granger, 720 Harmon Street, Columbus, Ohio 43223

NOTE: Company and product names are used in this table solely for the purpose of providing information. Mention of them does not constitute a guarantee by the U.S. Department of Agriculture or an endorsement by the Department over other products not mentioned.

Double Vane

One frequently encountered sampler design problem involves getting enough sample volume from a small even although not getting too much from a large event. If the proportional sampler collects one one-thousandth of the total runoff, a needed 1 cubic foot sample will be collected during a 1,000 cubic foot runoff event. But if the sampler collects at the same rate during a 10,000 cubic foot event, a 5 cubic foot container in the refrigerator would overflow and the concentration data from the sample would not be valid.

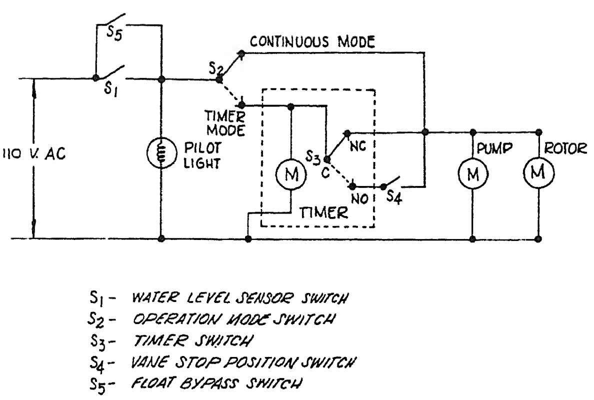

FIGURE 5.—Electrical schematic.

The electric timer (S3 of fig. 5) adds flexibility to the system, allowing the operator to change the proportion of the flow sampled by changing the proportion of the time the system is operating (for example, 1 minute out of every 5). This method of controlling sample size works well when experience allows the operator to preset switches S2 and S3 of figure 5 in the correct positions, but if S2 is in the continuous operation position (a small runoff event is expected) and a large event occurs, data will be lost. Conversely, not enough sample will be collected from a small event if the timer is set to handle a large event.

The double vane system (fig. 6) further increases the capability to sample either the largest event expected or the smallest event deemed significant. For the example shown in figure 6, two vanes are mounted opposite each other on the same vane shaft. The sampling path length (S of fig. 4) for one vane is five times as long at any radius as it is for the other vane, so the wide vane catches five times as much sample in any revolution or in any event. The catch from each vane is delivered to separate containers by two concentric funnels below the vane shaft.

The width of the vane can be altered by varying S(1) of table 1. To make a narrow vane 1/Nth as wide as the original vane, calculate S(1) for the narrow vane with S(1)=S(1)/N. In the computer solution (app. A), the variable S1 controls vane width.

The wide vane is the small event sampler. Valve A of figure 1 is adjusted so that the wide vane collects the minimum volume of sample needed from the smallest runoff event to be sampled. When such an event occurs, the wide vane container will hold enough sample for analysis and the narrow vane container will hold one-fifth that amount. With a smaller event, the catch from both vanes may be combined for analysis, or the event is considered too small for transport to be significant.

When a big event occurs, the container for the wide vane will overflow and destroy the integrity of that sample; however, if that container is made large enough to hold five times the needed sample volume, the narrow vane will have caught enough sample for analysis at the time the wide vane container overflows. So for large events, the sample for analysis is collected from the narrow vane container, which fills at one-fifth the rate of the wide vane container.

Calibration and Testing

A calibration check of the assembled system can be made by comparing the catch at several gage heights (GH) with the theoretical catch based on the weir rating table. If a width adjustment is needed, the upper edge of the vane can be moved slightly with spacers or by bending the lip of the vane with pliers. As shown in table 3, vane calibration is by ratios. Gage heights were selected with corresponding flow rates that

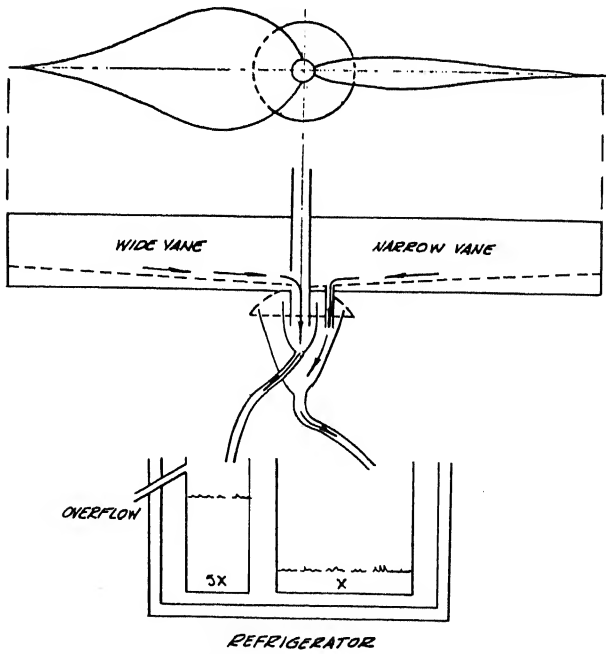

FIGURE 6.—Schematic of the flow system for the double vane system.

Table 3.—Calibration check of vane sampler

Gage height	Flow rate	Revolutions	Sample catch Theoretical	Actual
Feet	*Ft³/s*	*Number*	*In³*	*In³*
2.82	81.2	1	34.8	34.8
2.18	40.6	2	34.8	34.8
1.65	20.3	4	34.8	34.8
1.27	10.2	4	17.4	17.5
.98	5.11	8	17.4	17.3
.74	2.52	16	17.4	17.4
.57	1.26	32	17.4	17.3

differ by a factor of two. This makes field checking easy because the catch at any position should be the same as at the two adjacent positions with twice or half as many revolutions. By positioning the float manually at the desired gage heights, the pump outfall can be correctly positioned for testing.

The measured catch for *one* revolution at the highest check point (34.8 inches³ at GH=2.82 feet, table 3) is recorded as the actual catch and becomes the theoretical base value for determining the proper catch at lower check points. At GH=2.18 feet, the flow rate from the rating tables is exactly half that at 2.82 feet, so the catch must be half. With the float lowered to 2.18 feet, the catch for *two* revolutions must be 34.8 inches. The catch at all other check points and at as many additional intermediate points as accuracy warrants is determined in the same way. The acceptable difference between actual and theoretical catch will be influenced by the sampling objective.

This method of checking calibration is valid if the pump delivery rate is not affected by flow

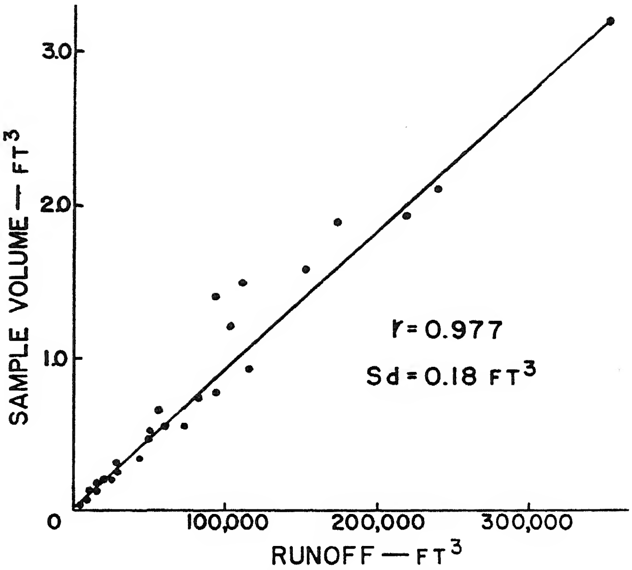

FIGURE 7.—Sampler performance at Coshocton Weir 182 during 1975.

stage. However, changes in pressure head on the pump, sediment load, entrained air, or water temperature could influence the pump delivery, which would affect proportionality. Field checks of the pump output at different stages show these effects to be small at the Coshocton sites.

Figure 7 shows the performance of the Coshocton vane sampler in operation at a 69.6 acre watershed during 1975. The least squares line through the plotted points indicates that the sampler consistently caught about one one-hundred thousandth of the flow through weir 182. The demonstrated precision also indicates that the sampled volume can be used to estimate runoff volume when the normal measuring system fails.

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APPENDIX

APPENDIX A. FORTRAN IV PROGRAM FOR CALCULATING VANE DIMENSIONS

```
C      SAMPLER VANE DESIGN
C
C
C      N = NUMBER OF GAGE HEIGHT-CFS PAIRS OF INPUT
C      V = APPROXIMATE VANE LENGTH
C      LOC = SITE NUMBER
C      GH( I ) = GAGE HEIGHT READ IN IN FEET, THEN CONVERTED
C              IN STATEMENT 10 TO INCHES
C      FS(I ) = FLOW RATE FROM RATING TABLE FOR GH( I )
C      GHM = MAXIMUM GAGE HEIGHT DESIGNED FOR ...  = GH( N )
C      WL= LENGTH OF WAND BETWEEN TAPE AND OUTFALL
C      X( I ) AND Y( I ) = COORDINATES OF OUTFALL AT GH( I )
C     S( I ) = LENGTH OF THE ARC AT RADIUS D( I ) SUBTENDED BY
C             THE SIDES OF THE VANE
C       WIDTH( I ) = CHORD FOR S( I )
C       DIST( I ) = DISTANCE FROM VANE PIVOT POINT TO MIDPOINT OF WIDTH( I )
C
C
       DIMENSION GH( 20 ), CFS( 20 ), A( 20 ), C( 20 ), X( 20 ), Y( 20 ), D( 20 ), S( 20 ),
      1WIDTH( 20 ), DIST( 20 )
       READ( 5, 101 )N, V, LOC
  101  FORMAT( I5, F10. 5, I5 )
       READ( 5, 102 )( GH( I ), CFS( I ), I=1, N )
  102  FORMAT( 6( F4. 2, F8. 3 ))
       DO 10 I=1, N
   10  GH( I )=GH( I )*12.
       GHM=GH( N )
       HM=GHM/2.
       WL=GHM-V
       B= 866*GHM
      DO 11 I=1, N
       A( I )=HM-GH( I )
       CARG=A( I )**2+B**2
       C( I )=SQRT( CARG )
       Y( I )=A( I )-WL*A( I )/C( I )
       C( I )=C( I )-WL
       XARG=C( I )**2-Y( I )**2
   11  X( I )=B-SQRT( XARG )
C      DO 11 CALCULATES THE X AND Y COORDINATES OF THE OUTFALL AT GH( I )
C      PIVX AND PIVY ARE X AND Y COORDINATES OF PIVOT POINT OF THE VANE
C      VANE PIVOT POINT IS  PPY  INCHES AWAY FROM OUTFALL AT MAXIMUM
C      STAGE, WHEN MEASURED PARALLEL TO TAPE
C
C
       PIVX=X( N )
       PPY=1.
       PIVY=Y( N )-PPY
       DO 12 I=1, N
       SARG=( PIVX-X( I ) )**2+( PIVY-Y( I ) )**2
   12  D( I )=SQRT( SARG )
       S1=2. 51328*D( 1 )*CFS( 1 )/CFS( N )
       DO 13 I=1, N
       S( I )=S1*( CFS( I )/CFS( 1 ) )*( D( I )/D( 1 ) )
       TARG=S( I )/( 2. *D( I ) )
       WIDTH( I )=SIN( TARG )*2. *D( I )
   13  DIST( I )=COS( TARG )*D( I )
       WRITE( 6, 201 )LOC
  201  FORMAT( 1H1, ///, 10X, 'SAMPLER VANE DIMENSIONS FOR WEIR ', I3 )
       WRITE( 6, 202 )GHM
  202  FORMAT( 1H , 10X, 'MAXIMUM STAGE DESIGNED FOR = ', F6. 2, ' INCHES' )
       WRITE( 6, 204 )D( 1 )
  204  FORMAT( 1H , 10X, 'LENGTH OF VANE =', F6. 2, ' INCHES' )
       WRITE( 6, 205 )WL
  205  FORMAT( 1H , 10X, 'OUTFALL IS', F6. 2, ' INCHES FROM END OF WAND' )
       WRITE( 6, 206 )
  206  FORMAT( 1HO, /, 10X, 'STAGE        FLOW      SAMPLING      DISTANCE FROM
      1 VANE WIDTH', /, 10X, '( IN. )', 5X, '( CFS )     RADIUS( IN. )    PIVOT ( IN. )'
      2, 8X, '( IN. )', / )
       WRITE( 6, 207 )( GH( I ), CFS( I ), D( I ), DIST( I ), WIDTH( I ), I=1, N )
  207  FORMAT( 1HO, F13. 2, F11. 3, F10. 2, F15. 3, F16. 3 )
   99  STOP
       5ND
```

APPENDIX B. SAMPLE INPUT AND OUTPUT FOR APPENDIX A PROGRAM

INPUT

1.75 23.6 2.00 32.7 2.25 44.2 2.50 59.3 2.75 76.4 3.00 94.7 #3

.25 .180 .50 .903 .75 2.61 1.00 5.39 1.25 9.79 1.50 15.9 #2

12 18.0 999 #1

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

OUTPUT

SAMPLER VANE DIMENSIONS FOR WEIR 999
MAXIMUM STAGE DESIGNED FOR = 36. 00 INCHES
LENGTH OF VANE = 17. 21 INCHES
OUTFALL IS 18. 00 INCHES FROM END OF WAND

STAGE (IN.)	FLOW (CFS)	SAMPLING RADIUS(IN.)	DISTANCE FROM PIVOT (IN.)	VANE WIDTH (IN.)
3. 00	0. 180	17. 21	17. 207	0. 082
6. 00	0. 903	15. 58	15. 580	0. 373
9. 00	2. 610	14. 11	14. 102	0. 977
12. 00	5. 390	12. 77	12. 737	1. 825
15. 00	9. 790	11. 51	11. 417	2. 983
18. 00	15. 900	10. 29	10. 058	4. 309
21. 00	23. 600	9. 03	8. 590	5. 563
24. 00	32. 700	7. 69	6. 978	6. 466
27. 00	44. 200	6. 23	5. 189	6. 896
30. 00	59. 300	4. 63	3. 267	6. 553
33. 00	76. 400	2. 87	1. 519	4. 880
36. 00	94. 700	1. 00	0. 309	1. 902

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